N 69 27941

NASA TECHNICAL MEMORANDUM

NASA TM X-1808

NASA TM X-1808

CAVITATION PERFORMANCE OF 80.6° HELICAL INDUCER IN LIQUID HYDROGEN

by Phillip R. Meng and Royce D. Moore

Lewis Research Center
Cleveland, Ohio

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • JUNE 1969

NASA TM X-1808

CAVITATION PERFORMANCE OF 80.6° HELICAL INDUCER IN LIQUID HYDROGEN

By Phillip R. Meng and Royce D. Moore

Lewis Research Center
Cleveland, Ohio

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

For sale by the Clearinghouse for Federal Scientific and Technical Information
Springfield, Virginia 22151 – CFSTI price $3.00

ABSTRACT

The cavitating and noncavitating performance of an 80.6° helical inducer was evaluated in liquid hydrogen over a temperature range from 31.0° to 40.2° R (17.2 to 22.3 K). The inducer was operated at 30 000 rpm at flow coefficients from 0.08 to 0.12. The net positive suction head requirements decreased with increasing liquid temperature; at constant temperature, these requirements increased rapidly with flow coefficient. At the lower values of flow coefficient and the higher liquid temperatures, the inducer produced a useful head rise even when operated with vapor at the inducer inlet.

CAVITATION PERFORMANCE OF 80.6° HELICAL INDUCER IN LIQUID HYDROGEN

by Phillip R. Meng and Royce D. Moore

Lewis Research Center

SUMMARY

The cavitating and noncavitating performance of an 80.6° helical inducer was evaluated in liquid hydrogen. The net positive suction head requirements were determined over a range of liquid temperatures and flow coefficients at a rotative speed of 30 000 rpm. The liquid temperatures ranged from 31.0° to 40.2° R (17.2 to 22.3 K). These tests were conducted over a flow coefficient range of 0.08 to 0.12. For a given percentage loss in noncavitating head rise, the required net positive suction head decreased at the higher liquid temperatures. At a constant liquid temperature, the required net positive suction head increased rapidly with increasing flow coefficient. For the lower values of flow coefficient at hydrogen temperatures of 36.5° R (20.3 K) and above, the data indicate that the inducer can produce a useful head rise while operating with vapor ingestion.

INTRODUCTION

A cavitating inducer in a rocket engine turbopump is designed to operate with a vapor cavity on the suction surface of the blades. For a given pump operating at fixed conditions of flow, speed, and inlet pressure, the size of this cavity is dependent on the degree of evaporative cooling that occurs at the liquid-vapor interface as a result of vaporization. Since vaporization involves heat transfer, the amount of cooling realized under given conditions is a function of the physical properties of the fluid and, thus, can change substantially with the fluid being pumped as well as with its temperature (refs. 1 to 7). Evaporative cooling causes the vapor pressure of the thin layer of liquid adjacent to the cavity to be reduced by an amount that corresponds to the local temperature reduction; cavity pressure is reduced by a corresponding amount. This reduction in cavity pressure retards the rate of further vapor formation, thereby allowing satisfactory operation of the inducer at lower net positive suction head than would otherwise be possible. (The net positive suction head NPSH is defined as the total pressure head above fluid vapor pressure head at the inlet.) The physical properties of liquid hydrogen change appreciably with temperature. Thus, the temperature of the hydrogen at the inlet of a pump has a major effect on its cavitation performance.

The objective of this investigation was to determine the net positive suction head requirements for an 80.6° helical inducer operating in liquid hydrogen over a range of liquid temperatures and flow coefficients. All tests were conducted at an inducer rotative speed of 30 000 rpm. Liquid temperatures ranged from 31.0° to 40.2° R (17.2 to 22.3 K) and flow coefficients from 0.08 to 0.12 (2400 to 3600 gal/min or 0.152 to 0.228 m^3/sec). The investigation was conducted at the Plum Brook Station of the NASA Lewis Research Center.

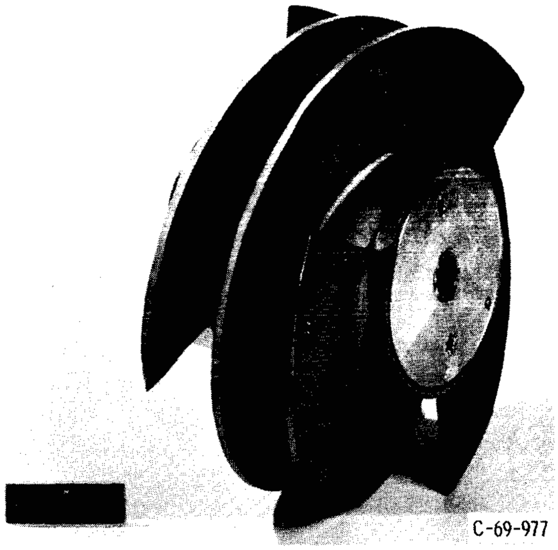
SYMBOLS

g	acceleration due to gravity, ft/sec^2 (m/sec^2)
ΔH	inducer head rise based on inlet density, ft (m) of liquid
NPSH	net positive suction head, ft (m) of liquid
U_t	blade tip speed, ft/sec (m/sec)
V_a	average axial velocity just upstream of inducer inlet, ft/sec (m/sec)
φ	flow coefficient, V_a/U_t
ψ	head-rise coefficient, $g\ \Delta H/U_t^2$
Subscript:	
NC	noncavitating

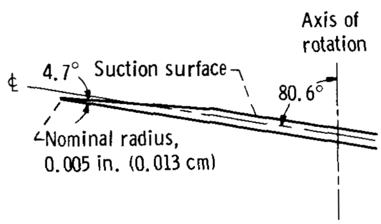
APPARATUS AND PROCEDURE

Test Rotor

The test rotor used in this investigation was a three-bladed flat plate helical inducer with a tip helix angle of 80.6° (angle measured from the axis of rotation). The inducer had a tip diameter of 4.980 inches (12.65 cm) and a hub- to tip-diameter ratio of 0.5. Both the tip and hub diameters were maintained constant across the rotor. The leading edges of the inducer blades were faired on the suction surface only. Significant geometric features, as well as a photograph of the inducer are shown in figure 1.



Tip helix angle (from axial direction), deg	80.6
Rotor tip diameter, in. (cm)	4.980 (12.649)
Rotor hub diameter, in. (cm)	2.478 (6.294)
Hub tip ratio	0.496
Number of blades	3
Axial length, in. (cm)	2.00 (5.08)
Peripheral extent of blades, deg	280
Tip chord length, in. (cm)	12.35 (31.37)
Hub chord length, in. (cm)	6.36 (16.15)
Solidity at tip	2.350
Tip blade thickness, in. (cm)	0.100 (0.254)
Hub blade thickness, in. (cm)	0.190 (0.483)
Calculated radial tip clearance at hydrogen temperature, in. (cm)	0.025 (0.064)
Ratio of tip clearance to blade height	0.020
Material	6061-T6 Aluminum



Leading edge fairing

Figure 1. - Photograph and geometric details of 80.6° helical inducer.

Test Facility

This investigation was conducted in the liquid hydrogen pump test facility shown schematically in figure 2. The test facility is essentially the same as that described in detail in references 1, 3, and 8. A 6.0-inch (15.2-cm) diameter line from the storage dewar to the upper side of the tank was added to facilitate recirculation of the liquid, thereby allowing longer test times.

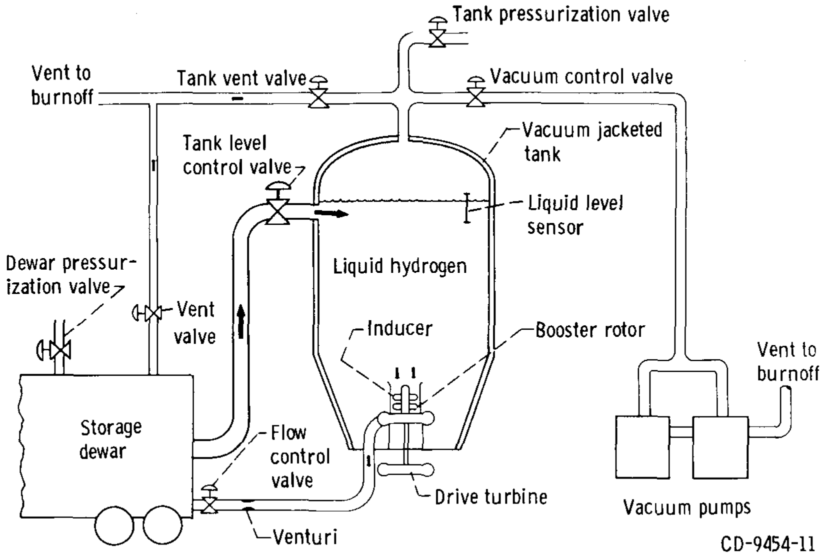


Figure 2. - Liquid hydrogen pump test facility.

The test inducer was submerged in liquid hydrogen near the bottom of the 2500-gallon (9.5-m^3), vacuum-jacketed, stainless-steel tank. The short inlet line extended approximately 3 inches (7.6 cm) above the inducer leading edges. A booster rotor, located downstream of the inducer, was used to overcome system losses. The flow path is through the test inducer and booster rotor to a collector scroll and into a 4.0-inch (10.2-cm) diameter line which discharges into a storage dewar.

Test Procedure

The 2500-gallon (9.5-m^3) tank was filled with liquid hydrogen from the 13 000-gallon (49.2-m^3) storage dewar. The hydrogen was preconditioned to the desired temperature prior to each test. For the colder hydrogen tests (below 36.5° R (20.3 K)), the tank pressure was reduced by use of vacuum pumps until the resulting evaporative cooling lowered the saturation temperature to the desired value. For temperatures greater than 36.5° R (20.3 K), the fluid was recirculated until the desired temperature was reached. For cavitating runs, the tank was initially pressurized to 10 psi (6.9 N/cm^2) above the liquid vapor pressure. For each test run the rotor was accelerated rapidly and the rotative speed stabilized at 30 000 rpm. Then the tank pressure (NPSH) was slowly reduced until the inducer head rise deteriorated significantly because of cavitation. The inducer flow rate and the bulk liquid temperature were maintained essentially constant during each test run. At liquid temperatures of 36.5° R (20.3 K) and greater, the hydrogen was recirculated from the tank to the storage dewar and then back into the tank. The tank liquid level was maintained by a level sensor that controlled the tank fill valve (see fig. 2). For test runs at liquid temperatures of 31.0° and 34.1° R (17.2 and 18.9 K) the hydrogen was pumped from the tank and into the storage dewar.

The noncavitating performance was obtained at a tank pressure of 15 psi (10.4 N/cm^2) above vapor pressure and a rotative speed of 30 000 rpm.

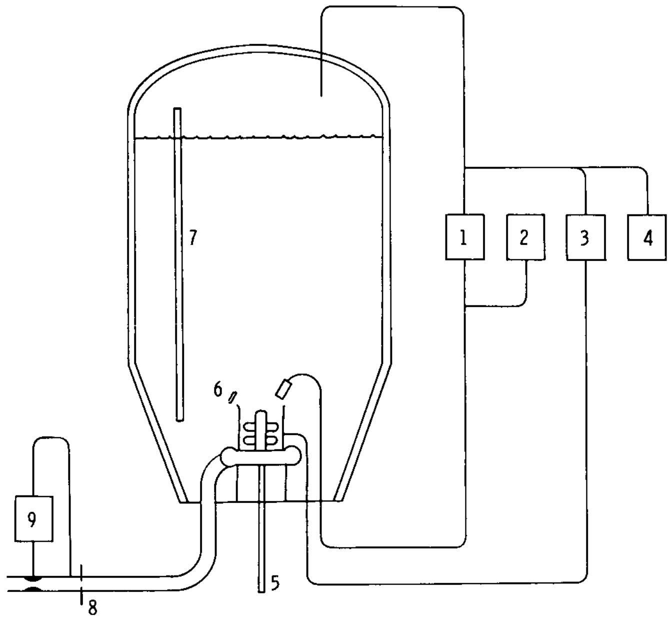
Instrumentation

The location of the instrumentation used in this investigation is shown schematically in figure 3. The measured parameters, number of probes used, and the estimated maximum system errors are listed in figure 3.

The liquid vapor pressure was measured at the entrance to the inlet line with a vapor pressure bulb which was charged with hydrogen from the tank. Tank pressure, measured in the ullage space, was used as the reference pressure for the differential pressure transducers. The liquid level above the inducer inlet, measured by a capacitance gage, was added to the reference pressure to correct the differential pressures to inducer-inlet conditions.

The differential pressure measured directly between the vapor bulb pressure and tank pressure was converted to head of liquid using the inlet fluid density and added to the tank liquid level to obtain NPSH at the inducer inlet. High and low range pressure transducers were used as required to obtain the desired accuracy of measurement. An averaged hydrogen temperature at the inducer inlet was obtained from two platinum resistor thermometers. A shielded total pressure probe located at midstream approximately 1-inch (2.54-cm) downstream of the test rotor was used to measure the inducer pressure rise.

Pump flow rate was obtained with a venturi flowmeter which was calibrated in water.



Item number	Parameter	Estimated system accuracy	Number used	Remarks
1	Net positive suction head (NPSH)	Low range: ±0.05 psi (0.035 N/cm^2) High range: ±0.25 psi (0.17 N/cm^2)	1 1	Measured as differential pressure (converted to head of liquid) between vapor bulb at pump inlet and tank pressure corrected to pump inlet conditions
2	Vapor pressure	±0.25 psi (0.17 N/cm^2)	1	Vapor bulb charged with liquid hydrogen from research tank
3	Inducer pressure rise	±1.0 psi (0.69 N/cm^2)	1	Shielded total-pressure probe at midpassage 1 in. (2.54 cm) downstream of inducer
4	Tank pressure	±0.5 psi (0.35 N/cm^2)	1	Measured in tank ullage and corrected to pump inlet conditions for use as reference pressure for differential transducers
5	Rotative speed	±150 rpm	1	Magnetic pickup in conjunction with gear on turbine drive shaft
6	Pump inlet temperature	±0.1° R (0.06 K)	2	Platinum resistor probes 180° apart at inlet
7	Liquid level	±0.5 ft (0.15 m)	1	Capacitance gage, used for hydrostatic head correction to pump inlet conditions
8	Venturi inlet temperature	±0.1° R (0.06 K)	2	Platinum resistor probes 180° apart upstream of Venturi
9	Venturi differential pressure	±0.25 psi (0.17 N/cm^2)	1	Venturi calibrated in water

Figure 3. - Instrumentation for liquid hydrogen pump test facility.

RESULTS AND DISCUSSION

Noncavitating Performance

The noncavitating performance is defined as that which shows no measurable change in inducer head rise as the NPSH is either increased or decreased. The noncavitating head-rise coefficient ψ_{NC} decreases almost linearly with increasing flow coefficient φ as shown in figure 4. The head-rise coefficient varied from 0.16 at $\varphi = 0.08$ to 0.03 at $\varphi = 0.12$.

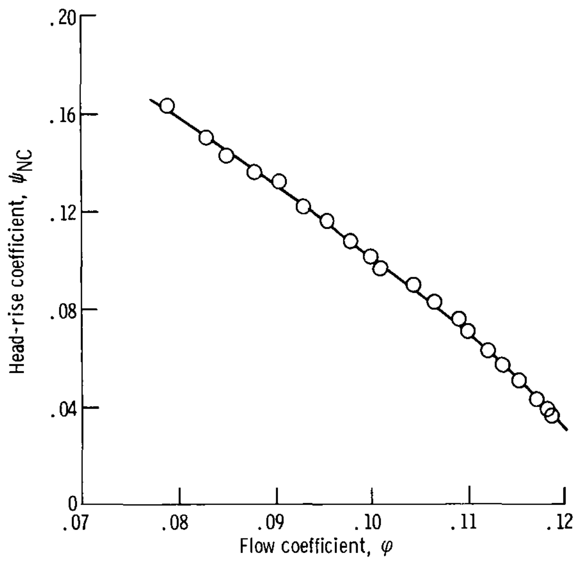
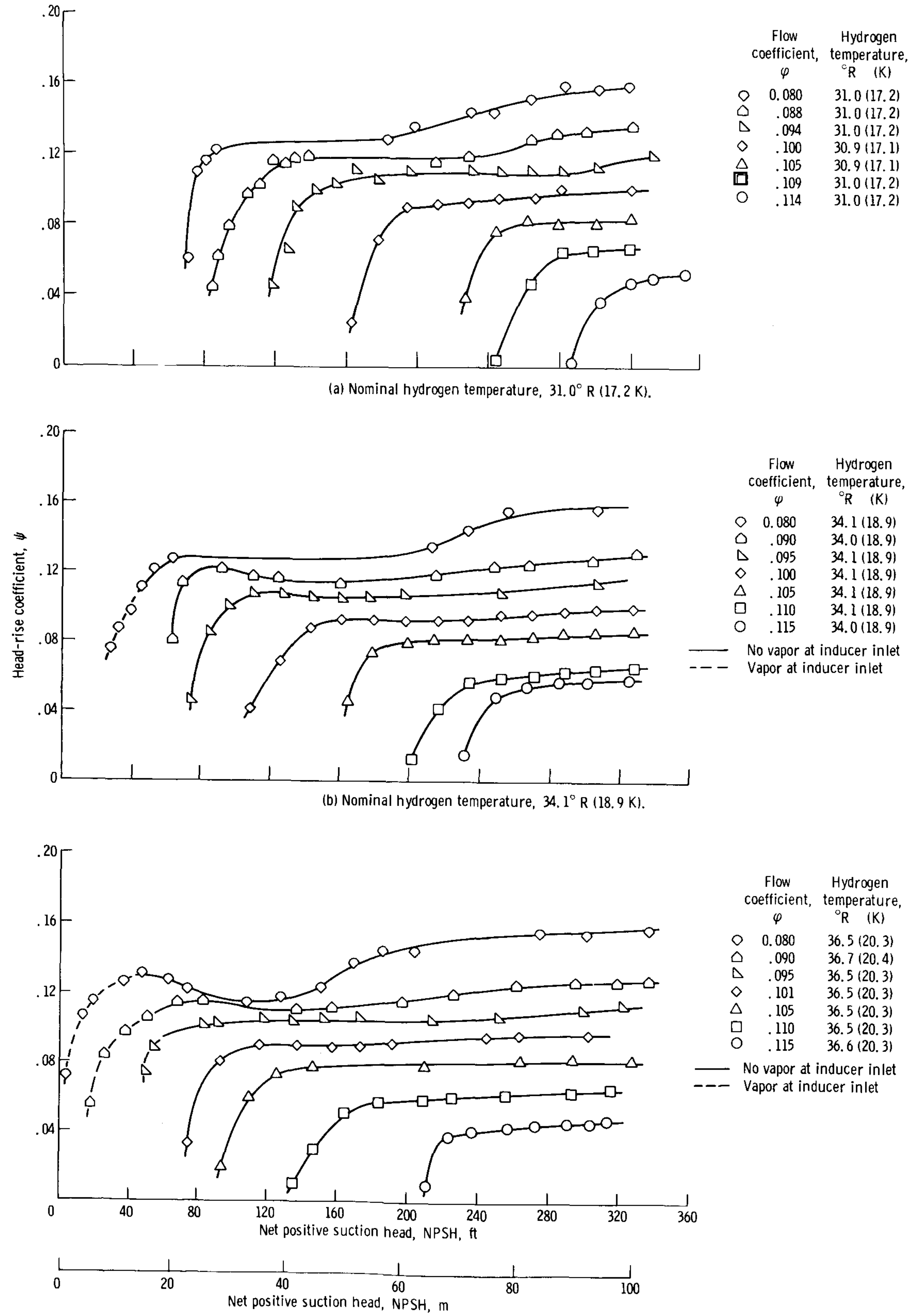


Figure 4. - Noncavitating performance of 80.6° helical inducer in hydrogen. Net positive suction head, >500 feet (152.4 m); rotative speed, 30 000 rpm.

Cavitation Performance

The cavitation performance for the 80.6° helical inducer is presented in figure 5 in terms of head-rise coefficient ψ as a function of the NPSH measured at the entrance to the inlet line. Several values of flow coefficient are shown for each nominal hydrogen temperature. As the flow coefficient is increased for a given liquid temperature and performance level, the required NPSH increases. As the NPSH was decreased at lower values of flow coefficient, the head-rise coefficient, after an initial decrease, remained constant or increased slightly before an abrupt fall-off due to cavitation. For example,

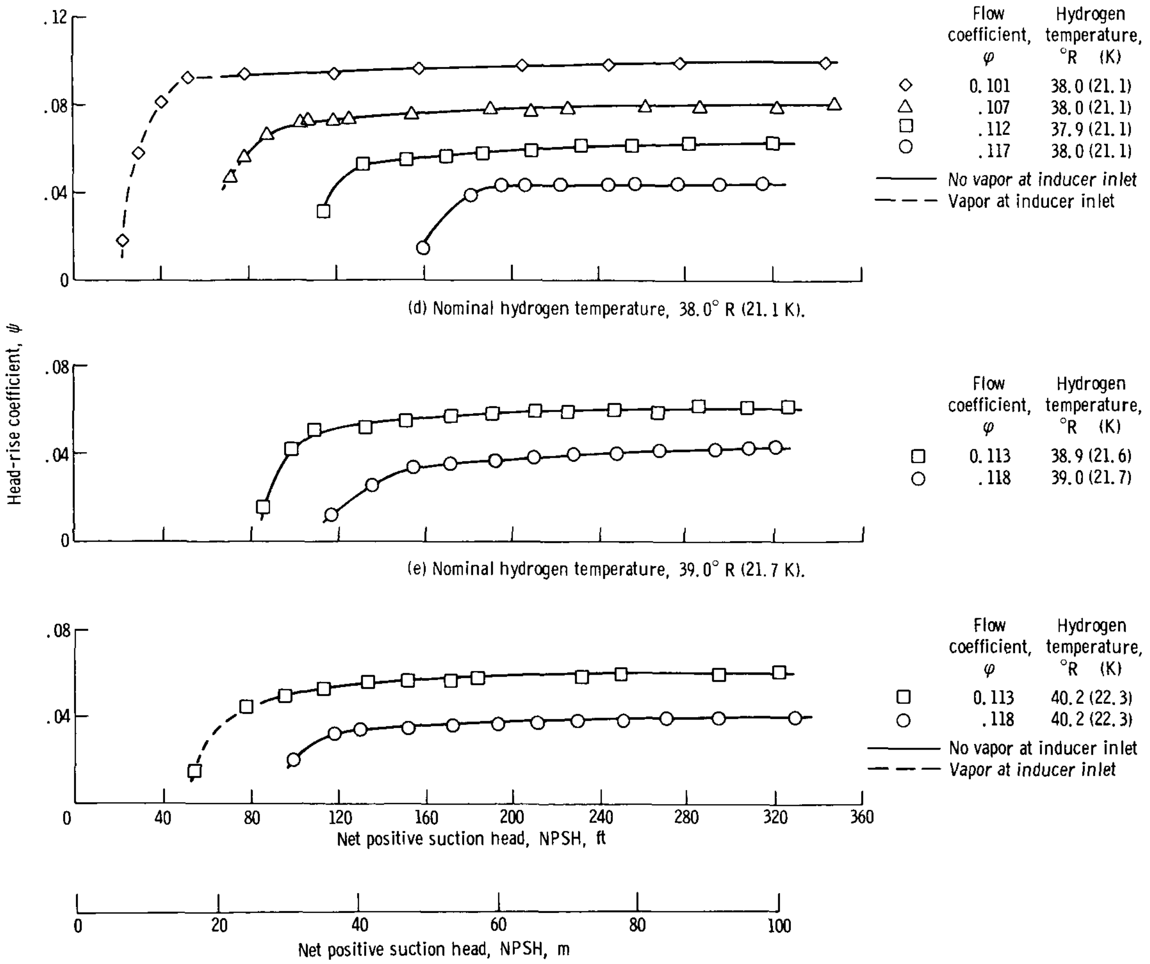


(a) Nominal hydrogen temperature, 31.0° R (17.2 K).

(b) Nominal hydrogen temperature, 34.1° R (18.9 K).

(c) Nominal hydrogen temperature, 36.5° R (20.3 K).

Figure 5. - Cavitation performance of 80.6° helical inducer in hydrogen at 30 000 rpm.



(f) Nominal hydrogen temperature, 40.2° R (22.3 K).

Figure 5. - Concluded.

in figure 5(a) for a flow coefficient of 0.08 and a temperature of 31.0° R (17.2 K), the head-rise coefficient decreased approximately 19 percent as the NPSH was decreased from 320 to 180 feet (98 to 55 m). As the NPSH was further decreased to 105 feet (32 m), the head rise remained essentially constant. At values of NPSH less than 105 feet (32 m) the head-rise coefficient fell off rapidly. This trend was noted for all values of flow coefficient less than 0.095 (figs. 5(a) to (c)).

The dashed portions of the curves in figure 5 represent the values of NPSH at which vapor formation occurs in the inducer inlet line. When the NPSH is lowered to the fluid velocity head, the local static pressure in the inlet equals the fluid vapor pressure and the hydrogen begins to boil. The resulting vapor is then ingested by the inducer. Since the flow coefficients for the curves of figure 5 were calculated based on all liquid flow, the effective flow coefficient for the dashed portion of the curves will be slightly greater because of vapor ingestion (see ref. 8). The data of figure 5 show that, for hydrogen

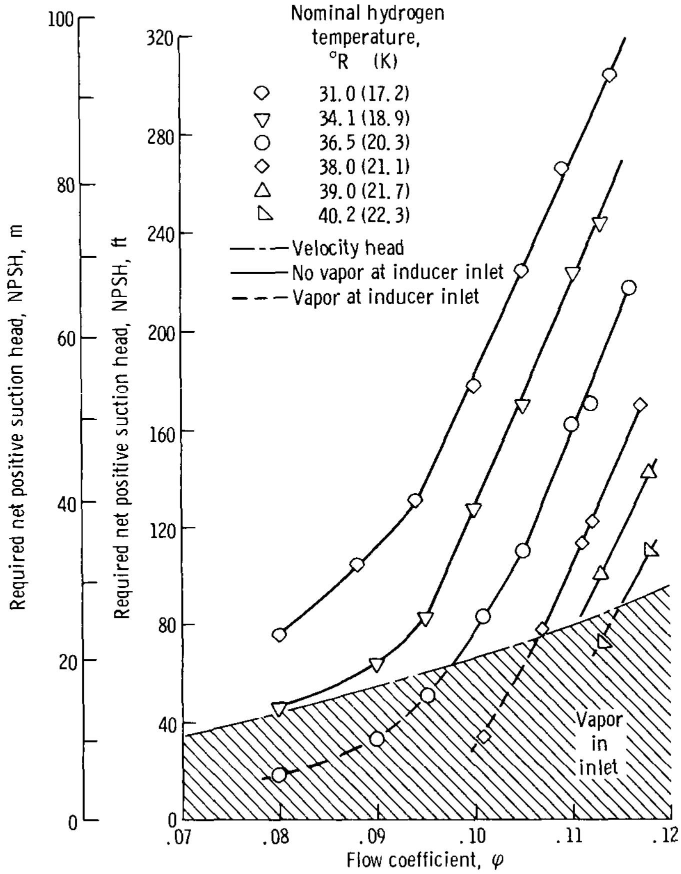


Figure 6. - Variation of inducer cavitation performance with flow coefficient at several hydrogen temperatures. Rotative speed, 30 000 rpm; head-rise coefficient ratio, 0.70.

temperatures of 36.5° R (20.3 K) and above, the inducer was capable of delivering a useful head rise while operating with vapor ingestion.

The required NPSH for a 0.70 head-rise coefficient ratio ψ/ψ_{NC} is plotted in figure 6 as a function of flow coefficient for several liquid temperatures. Values of NPSH less than the calculated velocity head $V_a^2/2g$ are indicated by the shaded area on this figure. The curves show that, for a constant flow coefficient, the required NPSH is significantly reduced as the liquid temperature is increased. For a constant liquid temperature the required NPSH increases rapidly with increasing flow coefficient. The dashed portion of the curves of figure 6 represent the values of NPSH that are equal to or less than the fluid velocity head at the inducer inlet. Thus, the data in the shaded area indicate that the inducer can operate at a head-rise coefficient ratio ψ/ψ_{NC} of 0.70 with vapor ingestion.

SUMMARY OF RESULTS

The noncavitating and cavitating performance of an 80.6° helical inducer was determined over a range of flow coefficients and liquid hydrogen temperatures. The net positive suction head requirements were evaluated over a liquid temperature range from 31.0° to 40.2° R (17.2 to 22.3 K) at an inducer rotative speed of 30 000 rpm. The flow coefficient was varied from 0.08 to 0.12 for these tests. The investigation yielded the following principal results:

1. As the hydrogen temperature was increased at a constant flow coefficient, the NPSH required to maintain a given performance level decreased significantly.

2. For a constant liquid temperature, the required NPSH increased rapidly with increasing flow coefficient.

3. For lower values of flow coefficient and hydrogen temperatures of 36.5° R (20.3 K) and above, the inducer produced a useful head rise while operating with vapor ingestion.

4. The noncavitating head rise decreased almost linearly with increasing flow coefficient. At a flow coefficient of 0.08, the head-rise coefficient was 0.16, and at a flow coefficient of 0.12, the head-rise coefficient was 0.03.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, April 10, 1969,
128-31-32-06-22.

REFERENCES

1. Ball, Calvin L.; Meng, Phillip R.; and Reid, Lonnie: Cavitation Performance of 84° Helical Pump Inducer Operated in 37° and 42° R Liquid Hydrogen. NASA TM X-1360, 1967.

2. Ruggeri, Robert S.; Moore, Royce D.; and Gelder, Thomas F.: Method for Predicting Pump Cavitation Performance. Paper presented at the Ninth Liquid Propulsion Symposium, Interagency Chemical Rocket Propulsion Group, St. Louis, Oct. 25-27, 1967.

3. Meng, Phillip R.: Change in Inducer Net Positive Suction Head Requirement with Flow Coefficient in Low Temperature Hydrogen (27.9° to 36.6° R). NASA TN D-4423, 1968.

4. Salemann, Victor: Cavitation and NPSH Requirements of Various Liquids. J. Basic Eng., vol. 81, no. 2, June 1959, pp. 167-180.

5. Spraker, W. A.: The Effects of Fluid Properties on Cavitation in Centrifugal Pumps. J. Eng. Power, vol. 87, no. 3, July 1965, pp. 309-318.

6. Stepanoff, A. J.: Cavitation Properties of Liquids. J. Eng. Power, vol. 86, no. 2, Apr. 1964, pp. 195-200.

7. Gelder, Thomas F.; Ruggeri, Robert S.; and Moore, Royce D.: Cavitation Similarity Considerations Based on Measured Pressure and Temperature Depressions in Cavitated Regions of Freon-114. NASA TN D-3509, 1966.

8. Meng, Phillip R.; and Connelly, Robert E.: Investigation of Effects of Simulated Nuclear Radiation Heating on Inducer Performance in Liquid Hydrogen. NASA TM X-1359, 1967.

NASA-Langley, 1969 — 28 E-5004